ARAGONITE SATURATION STATE AND DEEP-SEA CORAL DISTRIBUTION IN THE NORTHWEST HAWAIIAN ISLANDS

An Undergraduate Research Scholar Thesis

by

KELCI MILLER

Submitted to Honors and Undergraduate Research
Texas A&M University
in partial fulfillment of the requirements for the designation as an

UNDERGRADUATE RESEARCH SCHOLAR

Approved by
Research Advisor: Dr. Brendan Roark

May 2015

Major: Environmental Studies

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ABSTRACT

Aragonite saturation state and deep-sea coral distribution in the Northwest Hawaiian Islands.
(May 2015)

Kelci Miller
Environmental Studies in Geosciences
Texas A&M University

Research Advisor: Dr. Brendan Roark
Department of Geography

Seamounts play key roles in the ecology of deep-sea fauna acting as sites of high speciation and hence endemism, oases of biomass and biodiversity. Central to biodiversity are deep-sea corals (DSC), who serve as important habitat-forming organisms for invertebrates and fishes, yet the ecology and ecosystem function of DSC is not well understood. In addition, DSC and seamount communities are identified as habitats at highest risk from anthropogenic impacts. Fishing activities including trawling and long-lining are pressing anthropogenic threats. In addition to trawling, DSC communities are threatened by ocean acidification where coral species with calcium carbonate skeletons are expected to be severely impacted by reduced pH levels and a shoaling of the aragonite saturation (Ωarag > 1) horizon. In this study we look at the impact of trawling on DSC and potential recovery rates in the Northwestern Hawaiian Islands (NWHI) and the Emperor Seamount Chain (ESC). Our results characterize the water column chemistry (^{14}C, nutrient levels, pH and total alkalinity) at three different sites in order to determine ecosystem health. More specifically, we are measuring the total alkalinity through the water column at three areas categorized as previously trawled, currently trawled, and never trawled in the NWHI to define the aragonite saturation horizon and compare it to the current distribution of DSC. These aragonite saturation state measurements are among only a handful for this remote region

including the Papahānaumokuākea Marine National Monument serving as baseline measurements by which to compare to current DSC distribution patterns and help to predict the effect of future climate change on DSC ecosystems.

ACKNOWLEDGEMENTS

We thank the captain and crew of the R.V. Sikuliaq and the A.U.V. Sentry team from the Woods Hole Oceanographic Institution for their excellent support of our science mission. We thank Texas A&M University Undergraduate Research Scholars Program and the Texas Sea Grant for their financial support.

CHAPTER I

INTRODUCTION

Seamounts are thought to play key roles in the ecology of deep-sea fauna as they are sites of high speciation and hence endemism (e.g. Hubbs, 1959; de Forges et al., 2000), oases of biomass and biodiversity (Samadi et al., 2006), and thought to be larval sources for non-seamount habitats (McLain et al. 2009). Deep-sea corals (DSC) are among the dominant taxa (Genin et al. 1992, Rogers 1994, Probert et al. 1997), one of the most diverse invertebrate group on seamounts (Stocks 2004), and are important as habitat-forming organisms for invertebrates and fishes (e.g. Krieger and Wing, 2002, Buhl-Mortensen and Mortensen 2004). The ecology and ecosystem function of both seamount communities and seamount DSC communities are poorly known globally.

Central to seamount biodiversity are deep-sea corals (DSC) who are importance as habitat-forming organisms for invertebrates and fishes (e.g. Krieger and Wing, 2002; Buhl-Mortensen and Mortensen 2004). DSC are distinct in their ability to serve as a resource that is capable of supporting a high level of diversity amongst marine species and hence they are characterized as essential to deep-sea ecosystems for their ability to provide a natural habitat and food source for marine organisms, including many commercially important fish species. Because of their role as keystone species, any activity that damages DSC has negative impacts that extent beyond the corals themselves and into the surrounding ecosystem that dependents upon them. DSC often dominate seamount communities (Genin et al., 1992; Rogers 1994; Probert et al. 1997) and are one of the most diverse groups of invertebrates found on seamounts (Stocks 2004). Thus DSC make good model organisms for the study of recovery of seamount habitats. The sessile nature of DSC and the fact that they are also long lived, living for 100s to 1000's of years and are generally very slow growing, on the order of μm to mm per year (Roark et al., 2006; 2009) also make them particularity vulnerable to damage and would suggest very slow recovery rates. Given this fact, occurrences of natural disturbances are rare in the deep-sea and on seamounts.

However DSC still continue to be threatened and destroyed by multiple anthropogenic threats as a result of an increasing human population continually seeking a higher standard of living (Wattage et al., 2010). Large-scale disturbance to seamount coral communities is rampant, with DSC communities and seamount communities identified as two of the top four "deep-sea habitats at highest risk from anthropogenic impacts" (Ramirez-Llodra et al., 2011). Fishing activities including trawling and long-lining (e.g. Koslow et al. 2001, Clark and Rowden 2009), the precious coral trade (Tsounis et al. 2010), growing interest in deep-sea mining for cobalt-rich manganese crusts (e.g. Hein 2002, Hein et al. 2009), and ocean acidification (e.g. Guinotte et al. 2006) are pressing anthropogenic threats. Trawling can result in significant damage with impacts ranging from fragmentation up to the desctruction of large areas on the seafloor. Trawling has been equated to the clear cutting of tropical rain forest. If DSC are able to recover and at what rate is based on a variability of factor including their location, environmental factors, habitat suitability, and recruitment potential, among other factors. The selected study area of the Northwest Hawaiian Islands (NWHI) is in deep, more temperate areas so a longer recovery rate would be more likely (Rooper et al., 2010). Unfortunately the ecology and ecosystem function of seamount DSC communities are not well understood in part because of the difficulty and cost of doing research in the deep-sea. Incurring a similar a loss of habitat followed by a loss of biodiversity from so many critical areas may result in a sixth mass extinction with an estimated result in a 70% reduction of coral (Henry et al., 2013).

DSC are also a unique paleoclimate archive that can extend our observations of ocean dynamics and climate to periods well before the onset of instrumental records. DSC have only recently been studied using geochemistry and radiometric dating methods. However DSC can have extremely long life-span and are located through out the worlds ocean including intermediate water depths, making them an unique recorder of past climates and a good candidates for proxy development work. Given that many of these species of DSC can be accurately dated by radiometric techniques and that they grow in a tree-like fashion by depositing growth rings with several species having growth rates much less than 1mm yr^{-1} (Robinson et al., 2013), decadally resolved and perhaps even annually resolved records are possible with high resolution sampling techniques. Considerable efforts have been made over the last ~10 years to develop biogeochemical proxies that reflect past environments such that this information will yield quantitative *in-situ* records of local environmental conditions over the lifetime of a DSC. Thus DSC proxy records have the potential to address important questions such the role of ocean circulation, as well as nutrient and carbon cycling, in a changing climate system. However, systematic calibration efforts require *in-situ* environmental data, which can be difficult to find, especially in remote regions such as the Pacific Ocean. Our understanding of climate change would be improved with historical information on oceanic conditions. In the absence of instrumental data, some long-term records can be attained using long-lived (hundreds to thousands of years) DSC as climate archives (c.f. Prouty et al., 2014; Sherwood et al., 2014). Thus DSC proxy records have the potential to address important questions such as the role of ocean circulation, as well as nutrient and carbon cycling in a changing climate system, which may help us understand how climate change will affect the oceans in the future. More specifically a better understanding of ocean acidification is necessary in order to better predict what will happen to these DSC ecosystems as pH in oceans increase (Williams et al., 2010).

The consequences of climate change to marine ecosystems include broad scale impacts that will affect even remote areas, and are not limited to increasing water temperatures. One third of the continually rising atmospheric CO_2 released from anthropogenic burning of fossil fuels is being absorbed by oceans (Robinson et al., 2013) resulting in more acidic conditions (Orr et al., 2005; Sabine and Feely, 2007). Ocean acidification is harmful to marine ecosystems while CO_2 decreases pH and the calcium carbonate saturation state. These alterations lower the capacity of coral building structures as lower carbonate ion concentration results in lower rates of calcification. These changes in the water column chemistry will also change the aragonite saturation state. The effects of 'ocean acidification' are not well understood, but species with calcium carbonate (aragonite or calcite) skeletons, such as corals and mollusks, are expected to be severely impacted by reduced pH (Hoegh-Guldberg et al., 2007). Aragonite saturation (Ωarag > 1) and dissolved oxygen decrease with depth and may limit coral distributions. The Ωarag saturation horizon is shallower and dissolved oxygen levels are lower in the North Pacific region than in the North Atlantic Ocean. Under-saturation of aragonite is expected to occur in waters occupied by deep-sea corals by the end of this century (Turley et al., 2007). While this is expected to have a negative impact on ocean biota including DSC, the outcomes are uncertain since some DSC taxa already exist in under-saturated conditions in some instances (Thresher et al., 2011). A lack of data on aragonite saturation and DSC distributions, especially in remote regions, hinders accurate predictions of ocean acidification impacts on DSC and seamount communities.

As the aragonite saturation state shoals, corals are less likely to grow at these depths (Thiagarajan et al., 2013). The shallower depth of aragonite saturation in the Pacific (< 600 m) compared with the North Atlantic (> 2000 m) has been suggested as a factor limiting deep-sea scleractinian distribution and abundance in the Pacific (Guinotte et al., 2006; Koslow 2007), but little empirical data exists on either aragonite concentrations or DSC in most parts of the Pacific. The lower dissolved oxygen in the deep Pacific (Smith and Demopoulos 2003) compared with the Atlantic may further limit DSC abundance and distributions (Davies and Guinotte 2011). Collectively, carbon dioxide, oxygen levels, and surface ocean productivity are the likely controls on determining DSC distribution as a result of organic matter accumulation in the water column;. These effects also place stress on corals because of the increased temperature and changes in the water column chemistry where hypoxia can occur. Impacts stemming from ocean acidification are not only directly linked to a specific change but may also result from other supplementary processes within the ecosystem (Pfister et al 2014).

It is unknown how long it would take for DSC to recover if trawling were stopped or for that matter if they would even then be able to recover. A study done in the Aleutian Islands estimated recovery rates on corals post trawling with bottom trawl surveys performed between 1997-2010 with 2,445 of tested trawls performed being used to calculate recovery rate predictions. 22 trawls resulted as specific to coral findings within these studies with 11 different families of coral while findings included a catch rate range of 0-188 kg ha^{-1}, and an average of 26 kg ha^{-1}. Observed natural recovery occurred at a rate of .062 yr^{-1} with the best growth rates seen in zones without trawling. There was 67% mortality rate of corals and 80% of the naturally existing corals were predicted to redevelop after 34 years (Rooper et al., 2010). This study suggests long-term recovery rates are to be expected based on these findings with evidence further supporting the hypothesis that corals are clearly slow developing and long-lived even in comparison to other related species that were impacted by the same trawling impacts.

Williams et al., (2010) also conducted a 'test of recovery' between 1997-2006 around Australia with similar parameters to the Rooper et al., (2010) study where the three same categories were observed; previously trawled, still trawled, and never trawled. Rather than observing water column chemistry and predicting growth, the study viewed coral sites over a period of 5-10 years observing for new growths while recording sightings and conducting surveys. Changes were deemed as 'equivocal' and the corals were noted to have a 'low resilience' with some growth and some degradation across this time frame on previously trawled regions. As expected, trawled areas proved to be less likely to recover than those in which had never been trawled (Williams et al., 2010).

Determining recovery rates is challenging due to a lack of specific studies looking at DSC recovery patterns. These corals have also existed for 10's of thousands of years while the few studies having been performed cover only a brief fraction of their existence. The closest related knowledge to studies on coral recovery rates is suggested to be species in shallow Antarctic areas (Rooper et al., 2010). Not only are the studies on corals limited, there is also sparse environmental data, especially subsurface environmental data coverage in the Pacific Ocean. More water column data, especially in remote regions of the Pacific will help researchers better understand DSC ecosystems and better quantify the effects of damage and predict recovery times.

In this research we aim to better characterize the water column chemistry at a series of locations in the Northwestern Hawaiian Islands (NWHI) and the Emperor Seamount Chain (ESC) as part of a larger project to assess recovery times for DSC beds in the NWHI following ended trawling 30+ years ago. This survey covers a series of replicate seamounts in three trawling treatment types (never trawled, trawled and recovering, continued trawling) using the AUV Sentry. Detailed mapping, the presence/absence, and distribution of keystone DSC species will be determined for three seamounts in each treatment type over two research cruises. In addition, the biogeochemistry of the overlying water column will be characterized at each site using a CTD and collecting water samples. These water samples will be used to measure the nutrient concentration, pH, pCO_2, and total alkalinity in order to calculate the aragonite saturation state (Ω_A). This data will be compared to the limited amount of previously collected data in order to determine the impact of changing pH on DSC communities and to improve aragonite saturation state models for low nutrient environments of the NWHI.

Because these measurements will be part of only a handful of depth profiles across the region, this work will represent valuable additional data points. There are only a total of only ~1,800 observations at 50m for the most common parameters, such as oxyegen content, across the entire region over the last several decades recorded in the Ocean Atlas (National Oceanographic and Atmospheric Administration (NOAA)) database. The most recent total alkalinity measurements were conducted in the mid 2000s as part of the World Ocean Circulation Experiment (WOCE) in which two transects bound the region of study. Variables including salinity, temperature, dissolved inorganic compounds, total alkalinity, pH, nutrient concentration, and oxygen concentrations will all be measured to supplement the Pacific data as part of this project. The calculated aragonite saturation state will be compared to the measured values using this WOCE data and the results collected in this study will be used to improve the aragonite saturation state models for low nutrient environments of the NWHI. By measuring the total alkalinity through the water column at each of the three seamounts in the NWHI to define the aragonite saturation horizon and comparing it to the current distribution of DSC, these aragonite saturation state measurements will effectively double the amount data collected in this remote region that includes the Papahānaumokuākea Marine National Monument and will serve as baseline measurements by which to compare to current DSC distribution patterns and to predict the effect future climate induced changes in pH will have on DSC communities in the region. Because of the extensive impacts, seamounts and DSC communities are increasingly becoming a focus of management concern in the US and on the international stage (Watling and Norse, 1998; Rogers and Gianni 2010)

Our understanding of climate change would be improved with historical information on oceanic conditions. In the absence of instrumental data, some long-term records can be attained using long-lived (hundreds to thousands of years) DSC as climate archives (Smith et al. 2000; Heilkoop et al. 2002). These invaluable archives provide insight into past conditions, which may help us understand how climate change will affect the oceans in the future. Modern characterization of the biogeochemistry of the environment in which DSC are living are critical to effective proxy development and calibration.

CHAPTER II

METHODS

Data for this project was collected aboard the research vessel, R.V. Sikuliaq, during a research cruise November-December 2014 to a series of locations in the far Northwestern Hawaiian Islands (NWHI) and the Emperor Seamount Chain (ESC). A series of sites within three different treatment types, never trawled, trawled and recovering, continued trawling have been identified in the NWHI (Figure 1,). In the first of two research cruises to the NWHI, one site in the each of the three treatment types was surveyed; Yuryaku Seamount is still open to trawling, Bank 11 is recovering after trawling was banned ~30 years ago, and Pioneer Bank was never trawled (Figure 1, Table 1).

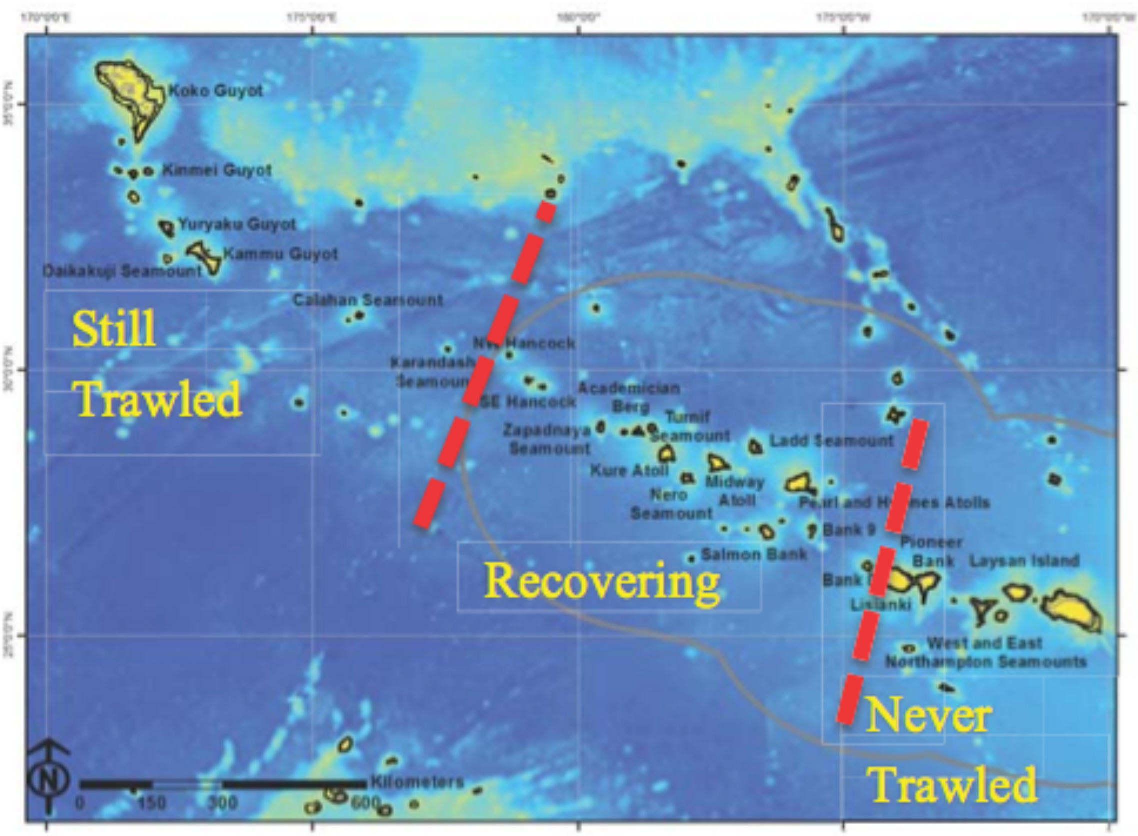

Figure 1. Map showing the northwest end of the Hawaiian Archipelago into the southern portion of the Emperor Seamount Chain. Red lines separate the treatment types.

Each site was mapped using a multi-beam sonar system aboard the R.V. Skikuliaq and photographic surveys were completed using the AUV Sentry. The water column was characterized using a CTD (conductivity, temperature, depth) and water samples were collected by a rosette of Niskin bottles at discrete bottom depths and at standard depths (e.g., 10, 50, 75, 100, 125, 150, ….., 1000, 1500, and 2000 meters as bathymetry allows). Waters were sampled for radiocarbon concentration, nutrients, and total alkalinity analysis back on shore. These processes result in detailed mapping of the abundance and distribution of keystone DSC species with the biogeochemistry of the overlying water column characterization from water samples from selected seamounts.

Table 1. Trawling impacts and surface area of features separated by treatment types with top group 'still trawled', middle group 'recovering', and bottom group 'never trawled'.

Feature Name	Posit Lat N	Posit Long E/W	*Last Year Trawled	Coral Obs	Total Catch **mt	SA (km^2)	Catch per km^2	C (km)
Koko Smt	35 15.0	171 35.0	Ong	ns	92500	3874	24	397.7
Yuryaku Smt	32 40.2	172 16.2	Ong	ns	98000	72.7	1348	41.2
Kammu	32 10.0	173 00.0	Ong	ns	28000	610.3	46	166.7
NW Hancock	30 16.2	178 43.2	1986 - ong	ns	98300	5.6	17558	9.2
SE Hancock	29 47.4	179 04.2	1986	ns	92500	10.9	8525	16.3
Zapadnaya	28 54.0	-179 36.0	1977	Yes	11500	42.3	272	33.2
Pioneer Bank	26 00.0	-173 26.0	Never	Yes		143.0		103.1
W Northampton	25 30.6	-172 24.6	Never	ns		81.48		85.8
E Northampton	25 22.2	-172 04.2	Never	ns		37.96		53.7

At each site the first phase of work begins with mapping with multi-beam sonar along evenly spaced transects to develop high-resolution bathymetry maps to aid in site selection planning for both CTD casts and AUV Sentry surveys. Especially important in this process is the identification of steeply sloped areas that are difficult for the AUV to navigate. Once the terrain is characterized, three AUV Sentry dives are planned based on potential areas of interest around the seamount that are beneficial for identifying benthic fauna, species, and families and most importantly documenting DSC presences, abundance, density, and habitat size. These surveys are performed at each site with downward camera surveys and additional instrumentation on the AUV that acquires CTD and oxygen data.

CTD casts take place at selected locations based upon previous mapping results targeted at a depth range of 300-600 meters, where trawling is most active and DSC are most common. CTD casts operate by taking samples using a rosette of individual Niskin bottles at set depths while additionally retrieving conductivity and temperature measurements simultaneously (Figure 2). Upon retrieval of the CTD equipment, samples are immediately transferred into clean, combusted glass bottles via tygon tubing placed into the base of the bottle to prevent mixing of air into the sample and then poisoned with mercuric chloride, to inhibit any biological growth during transportation, capped with glass stoppers and sealed with grease, and wrapped with electrical tape. The bottles are then stored and shipped to Texas A&M University for laboratory analysis for total alkalinity measurements. Water samples collected will also be used to measure pH, pCO_2, and total alkalinity in order to calculate the aragonite saturation state (Ω_A).

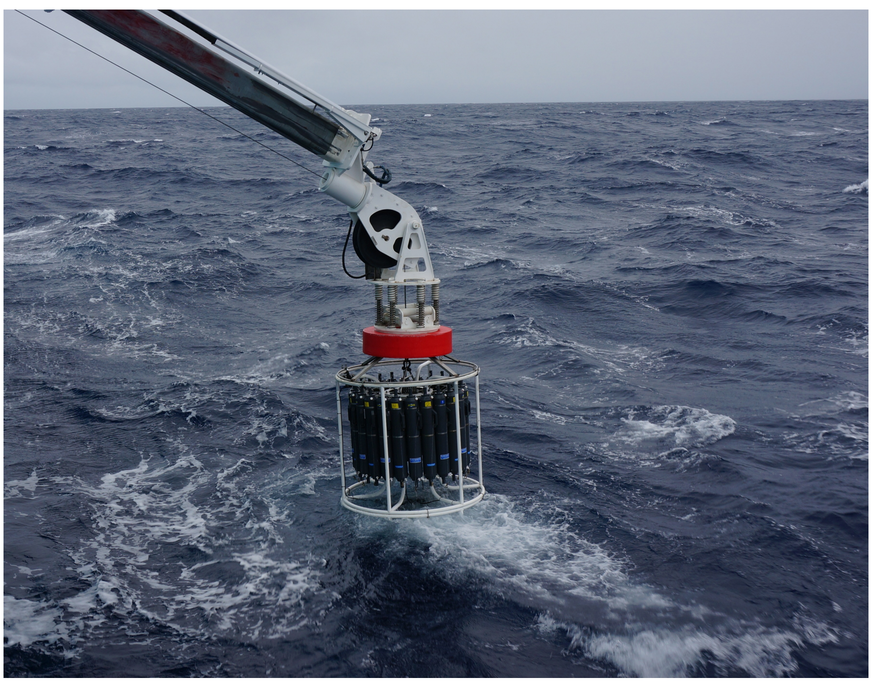

Figure 2. CTD system being deployed on the R.V. Sikuliaq for water column profiling and water sampling.

Samples collected from the CTD are transferred into 300ml glass bottles with room left for headspace and the placement of mercuric chloride solution, serving as an immediate inhibitor for biological activity during transit and delay for sample analyses. The total alkalinity (TA) measurements are the first done on the versatile instrument for the determination of titration alkalinity (VINDTA) analytical system by Marianda Marine Analytics and Data at Texas A&M University, also capable of retrieving dissolved inorganic carbon (DIC) measurements. While these are the first measurements, reliability is ensured by reproducibility of certified reference materials (CRMs) and unknown samples runs prior and periodically throughout analysis. Coulometric titrations and open cell potentiometric titrations produce TA and DIC results that can then be processed using Excel Workbook Visual Basic for Applications, a comprehensive evaluation of all collected variables including salinity, temperature, TA, and DIC.

CHAPTER III

RESULTS

Multi-beam sonar data was processed in real time aboard the ship and bathymetric maps along with maps of slope changes for Yuryaku Seamount (open to trawling)(Figure 3 and 4), Bank 11 (recovering)(Figure 5 and 6), and Pioneer Bank (never trawled) (Figure 7 and 8). These maps were used for dive planning and will eventually be married with photo survey analyses.

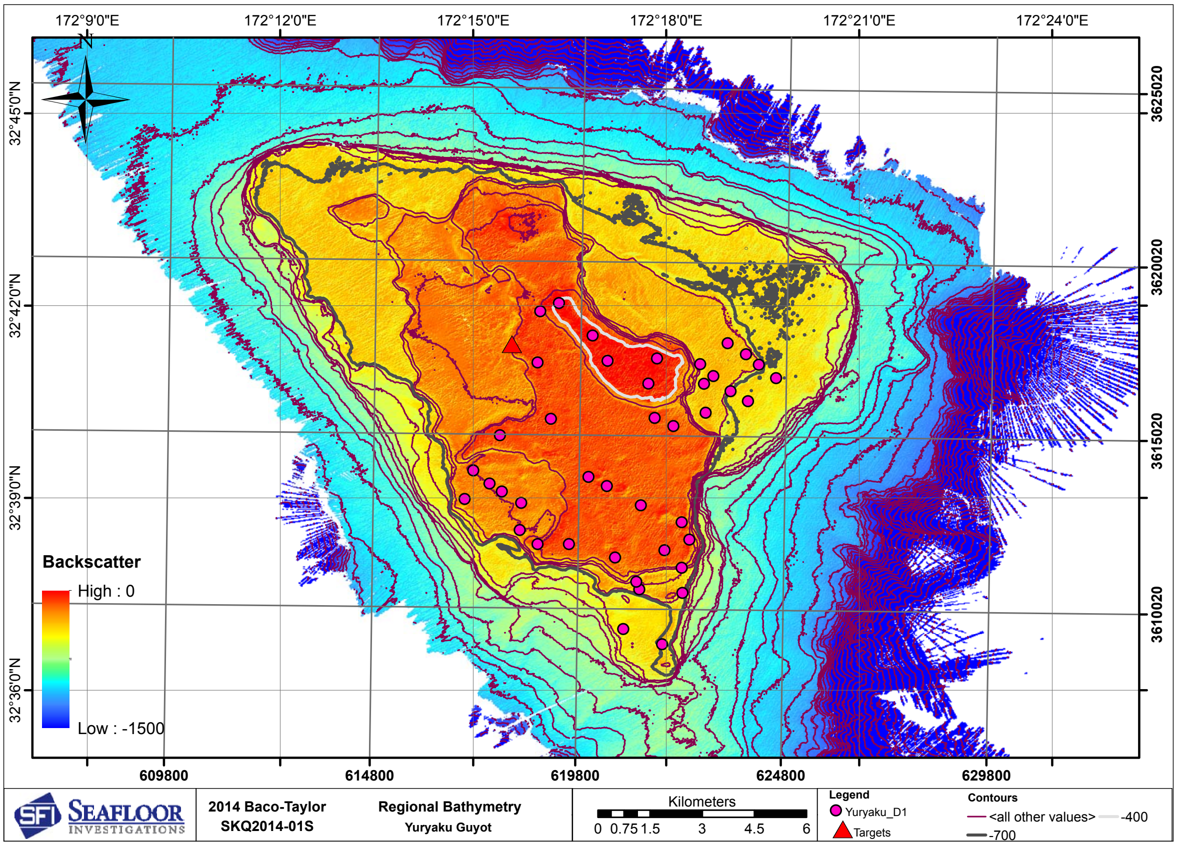

Figure 3. Yuryaku bathymetry mapped by multibeam sonar displays a mapped seamount at depths between 600 and 800 meters. Above 200 m, the structure appears to be relatively flat with open tops to the seamount surrounded by steeper sides in the prime coral habitat.

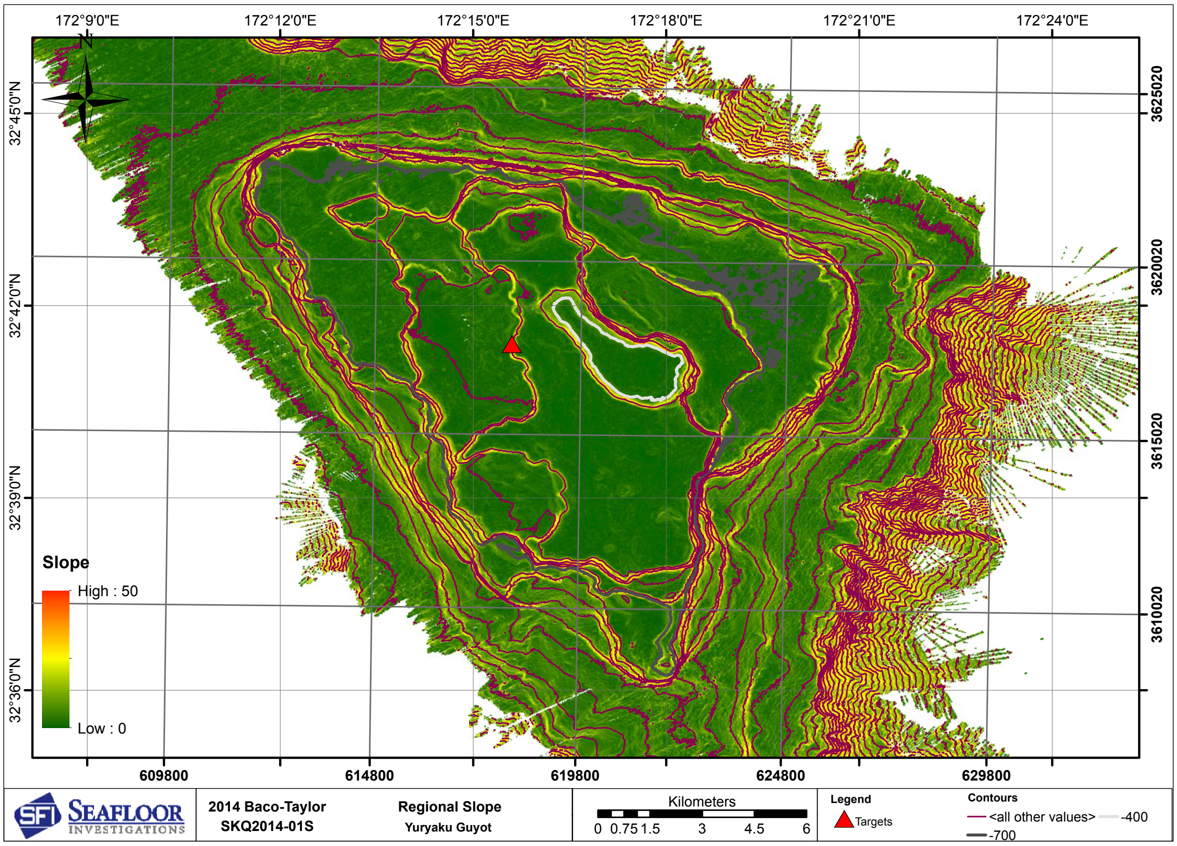

Figure 4. Bathymetry derived slope calculations show variations in slope from flat, 0%, up to as much as 50%. These contours suggest prime locations for vertical structures ideal to coral development. Major contours are shown in grey while less dramatic slope changes are shown in purple.

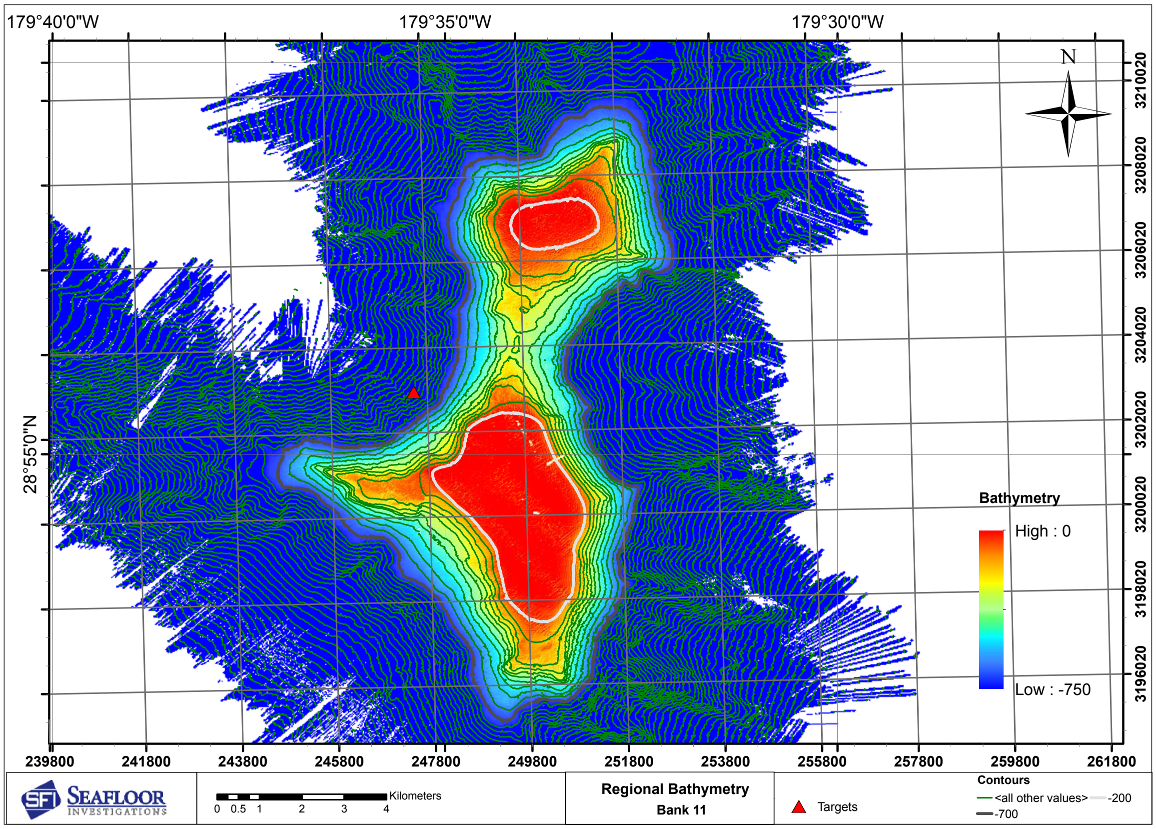

Figure 5. The Bank 11 bathymetry map demonstrates a lower sea floor with a gradual increase beginning at 500m before more rapidly rising into two separate yet paralleled seamounts. At 100-200m the structure levels out for each of the features that are about 400m apart.

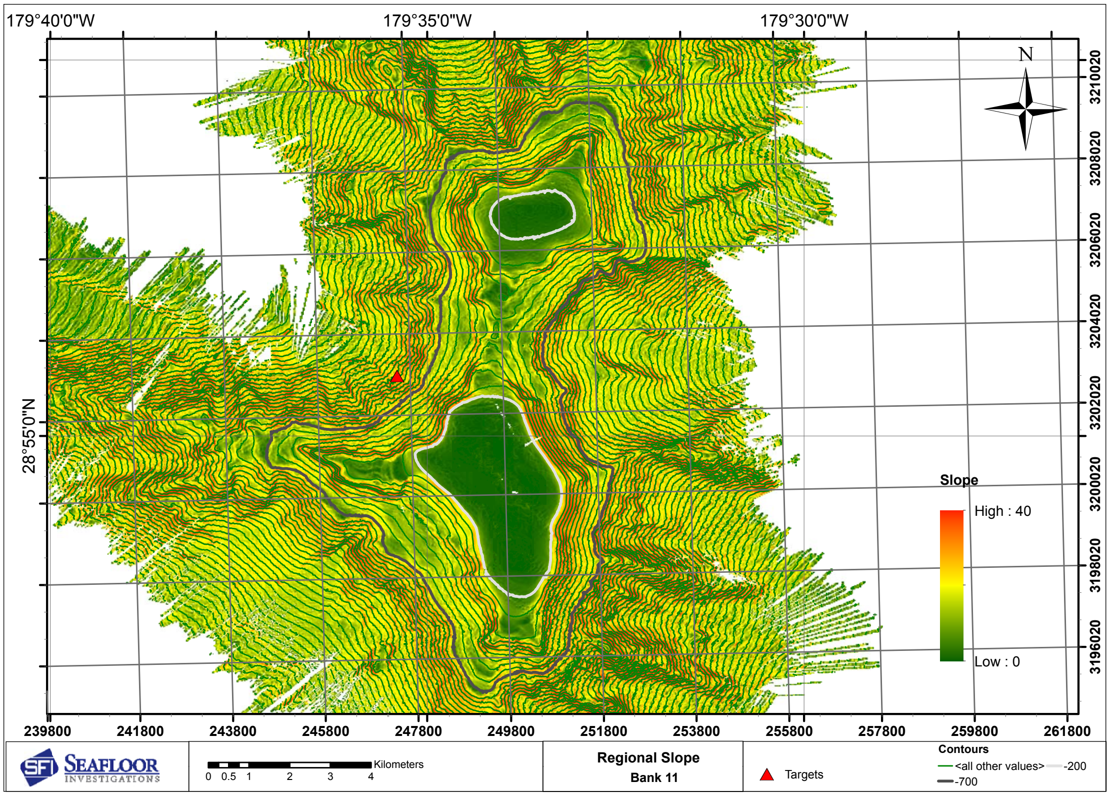

Figure 6. Bathymetry derived slope calculations show variations in slope from flat, 0%, up to as much as 40%. Light grey contour lines show -200 m, mostly visible around the upper portion of the seamount, while the more common dark grey show changes of -700m.

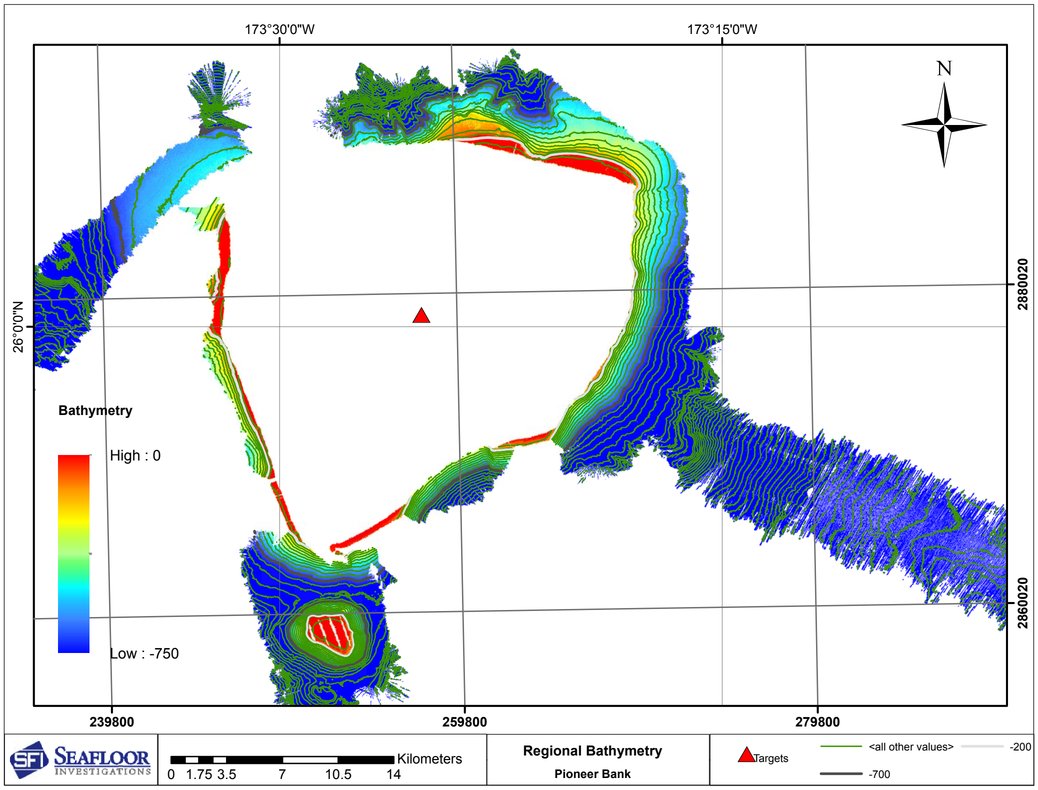

Figure 7. Given the amount of previous mapping done and size of Pioneer Bank, mapping was focused on the southeastern quadrant and across the primary depth ranges of interest (800-200m). Above 200m, central in the figure, the bathymetry appears to level out in contrast to its deep, rapidly sloped surrounding sides.

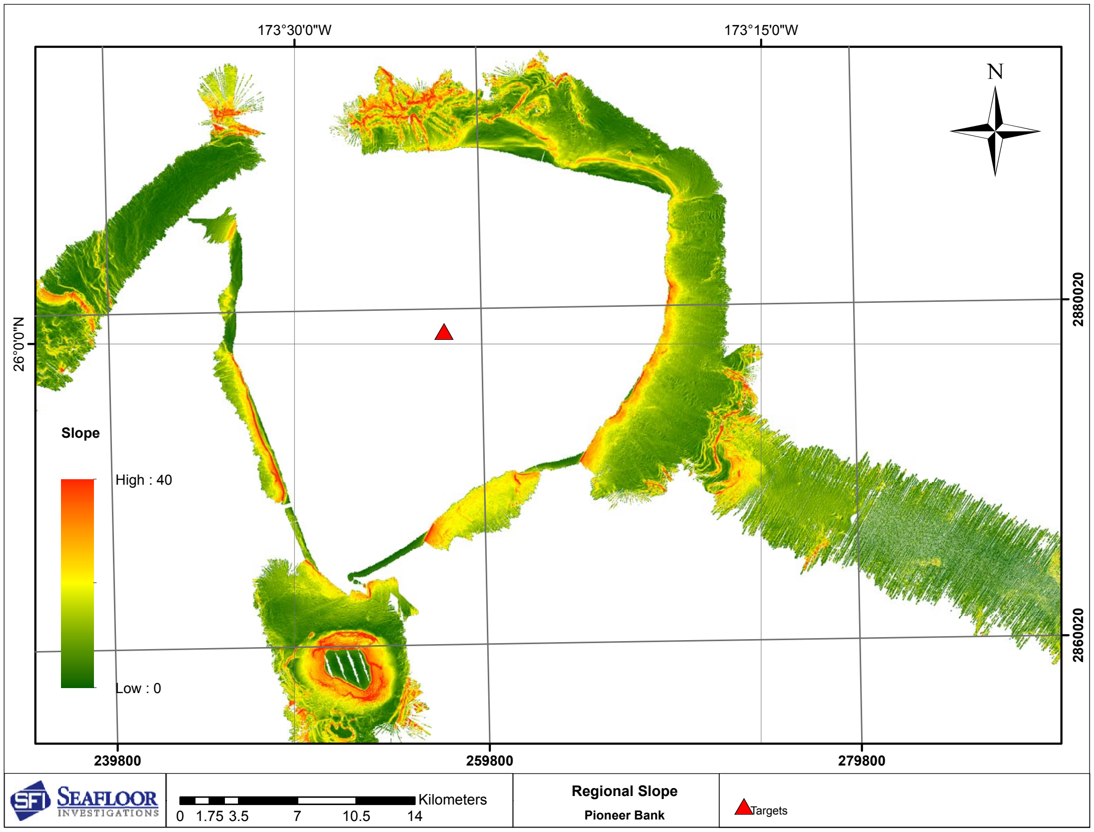

Figure 8. Bathymetry derived slope calculations show variations in slope from flat, 0%, up to as much as 40%. Contour lines shown in the northern most region show step, rapid changes in slope. These changes appear less heavily south of the targeted area with rise in elevation.

CTD profiles including salinity (PSU), temperature (°C), fluorescence or biological productivity (seapoint), and oxygen (ml/l) were completed and processed into 1 meter bins for Yuryaku Seamount (open to trawling)(Figure 9), Bank 11 (recovering)(Figure 9), and Pioneer Bank (never trawled) (Figure 9). While minor variations from location to location are present, overall we can see that these variables generally have the same pattern. Fluorescence consistently begins around 0.1-0.2 seapoint at the sea surface before reaching a high productivity level around 0.4-0.5 seapoint at a depth of 100 meters and then decreasing to almost 0.0 seapoint over the remainder of the water column. Salinity also starts at ~35 PSU at the surface before reaching a low of 34.1 PSU around 500-700 meters and continuing around ~34 PSU till the bottom is reached. There is a slight range in temperature at the surface between sites with surface temperature starting at 20°C for Yuryaku Seamount, and increasing to ~24°C for Pioneer Bank and Bank 11. At all three sites temperatures drop significantly through out the water column reaching a low of 3-4°C at the deepest depths. Oxygen levels start at the sea surface between 35.1-35.3 ml/l and peak in concert with fluorescence before dropping to 1-2 ml/l. The oxygen maximum zone lies between 200-700m deep, where expected aragonite saturation levels should allow corals to precipitate their skeletons. These measurements demonstrate a uniform and well-mixed upper 100m as a result of vertical mixing from storm activity and large wave heights experienced during the cruise.

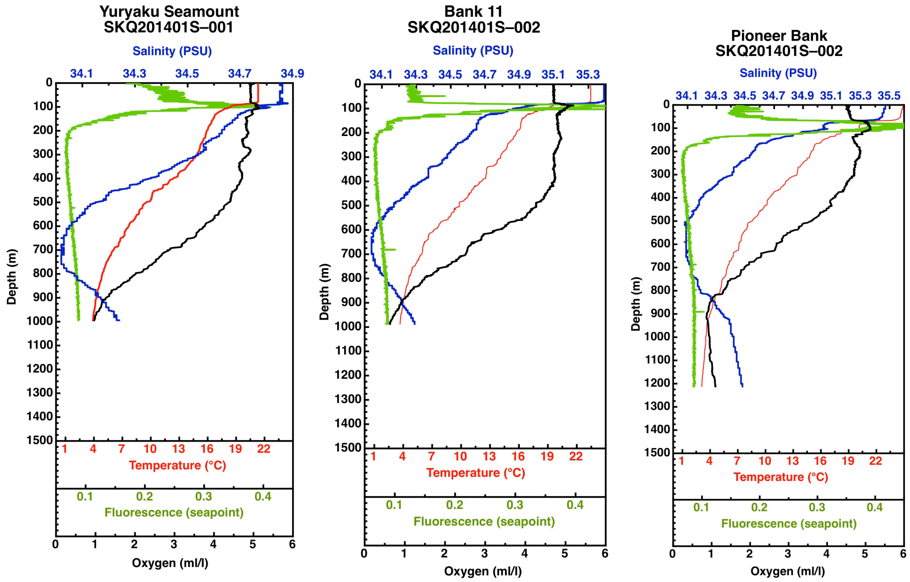

Figure 9. CTD casts taken at Yuryaku (0-1,000 m), Bank 11 (0-1,00 m), and Pioneer Bank (0-1,200 m), measures temperature (C) is shown in red, measure of biological activity is shown in green by fluorescence (seapoint), oxygen in black (mL/l), and salinity (PSU) in blue.

A very small subset of the AUV Sentry photos were quickly processed to identify the presence or absence of DSC and to determine if any damage from fishing activities could be found. Specific photos were selected from a movie that includes all photos taken during a AUV Sentry dive.

All nutrient and total alkalinity analyses are on going because of the large number of samples (more than 75 total alkalinity and 140 nutrient samples) and the complexity of the doing the analyses. The VINDTA analyzer was only installed and operational in January and yet is showing promising results with low backgrounds and very good reproducibility of certified reference materials. All analyses will be completed by end of April.

CHAPTER IV

DISCUSSION AND CONCLUSIONS

Sites for study were selected based on their exposure to anthropogenic fishing impacts whose range from never trawled, recovering and stilled trawled are unique. Because of the availability of a rare control as a result of the management and conservation efforts of the Papahanaumokuakea Marine National Monument there is a pristine, never trawled site. This grouping within the same seamount chain with sites that have been protected for over 30 years and thus represent long term recovery sites is ideal. Some of the heaviest trawling in the world, with trawling being one of the largest anthropogenic threats to the planet, has occurred within the Emperor Seamount Chain. This is a unique location to observe this problem additionally not only because of these heavy impacts but also for its high biodiversity, high habitat suitability, 50-70% of coral catch occurs for this region (Griggs 2002), and corals are vital to the fundamental recovery of communities as a whole.

Yuryaku Seamount was the first site visited and it had the largest amount of biomass of marine species removed as a result of fishing activities. As expected there are large areas of coral rubble indicative of the damage done by fishing activities (Figures 10 and 11). Bank 11 is currently recovering from trawling impacts with the most recent trawl taking place in 1977 and is now categorized as low take which will result in a longer recovery period. Quick review of the AUV Sentry photos did not show the same extensive damage as Yuryaku, nor were there easily identifiable living DSC of any size. Images Pioneer Bank, which resides within the protected monument's area as a never trawled, highly protected area with well-developed precious coral beds had several easily identifiable DSC (Figures 12 and 13). In fact there was an excellent example of what a well developed and diverse DSC coral bed looks like if no damage has occurred (Figure 14). Many of the DSC in this image have been living 100s in the case of pink corals, to 1000s of years in the case of Gold coral (Roark et al., 2006; 2009). While much more work remains to be done as part of the larger project, there preliminary results on the presence and absence of DSC clearly show that these sites are unique in their ability to quantify the decree of recovery a DSC ecosystem can achieve after multiple decades of no fishing.

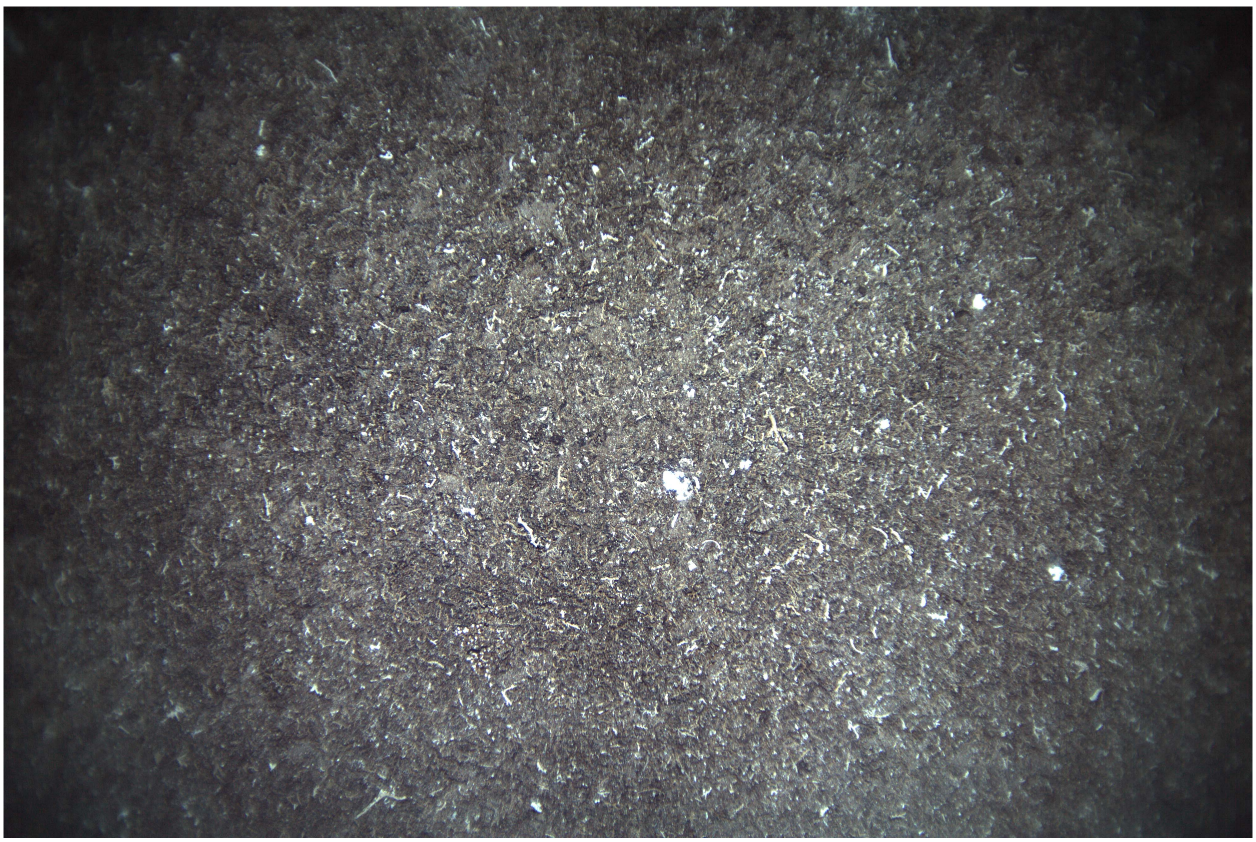

Figure 10. Recent and ongoing heavy trawling by fishing nets at Yuryaku seamount has resulted in DSC being removed, broken, and fragmented.

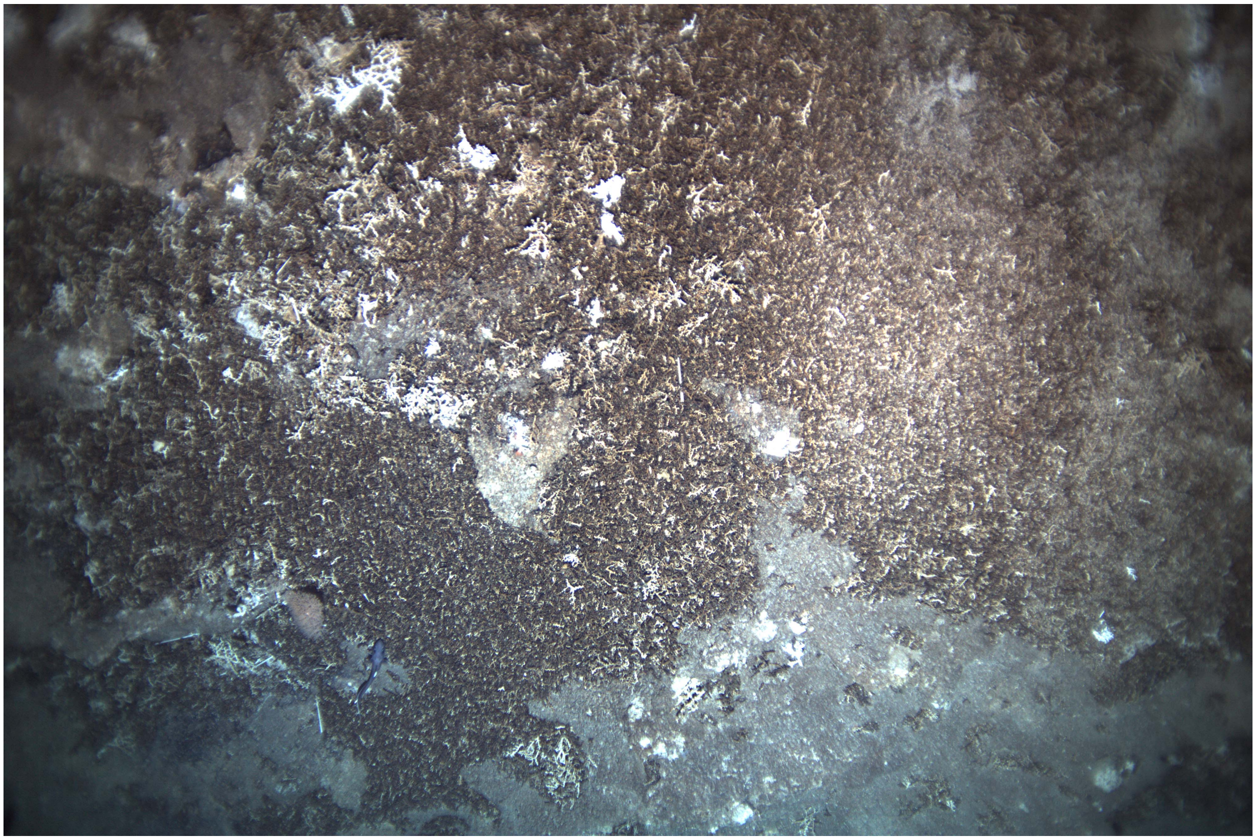

Figure 11. Recent and ongoing heavy trawling by fishing nets at Yuryaku seamount has resulted in DSC being removed, broken, and fragmented.

sentry.20141207.152354749849.7438.tif
2014-12-07 15:23:54 lat:25.8420725 lon:-173.4664406
depth:491.502m alt:5.93m hdg:75.31d
temp:7.9729C obs:0.119155V

Figure 12. Individual deep-sea coral at Pioneer Bank.

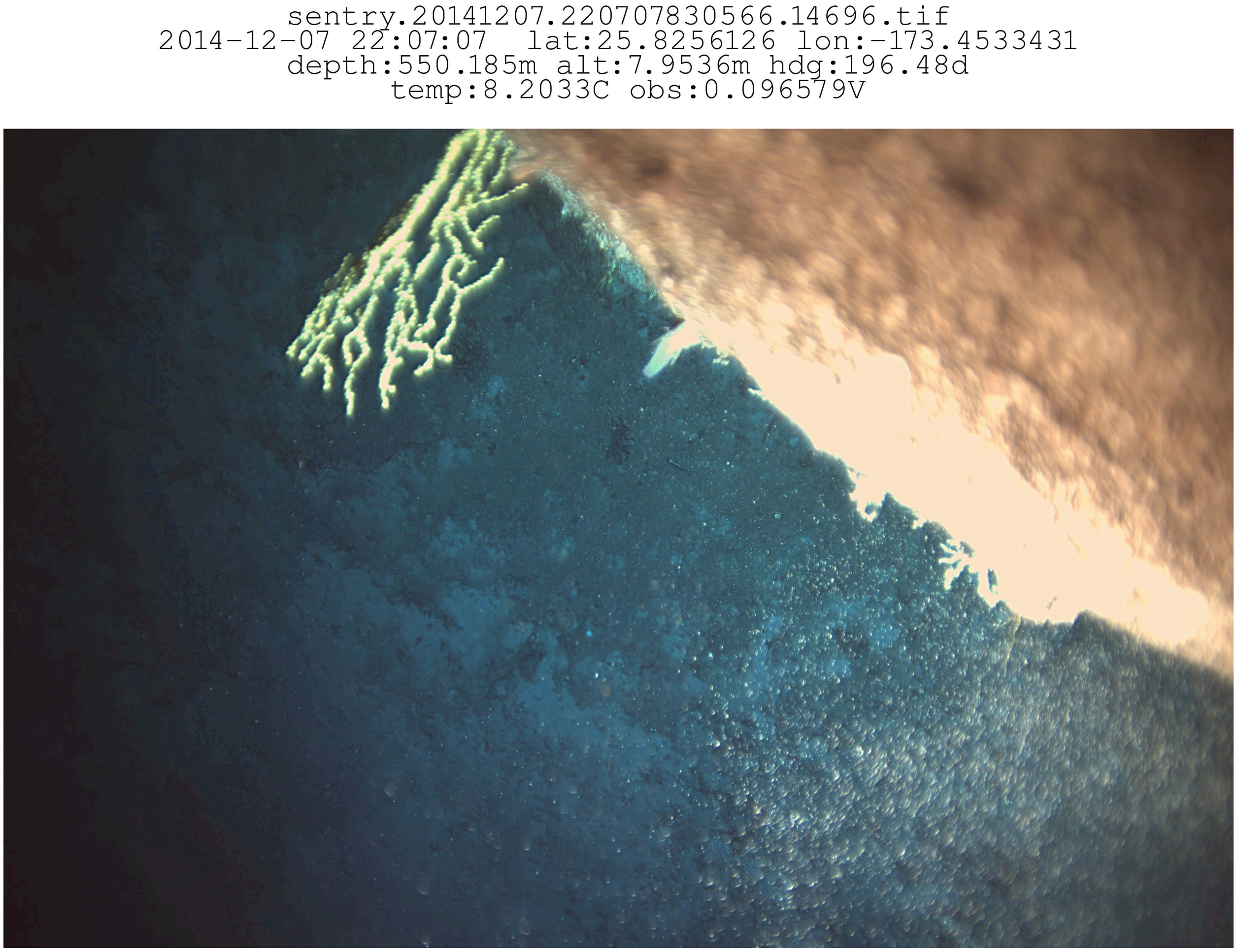

Figure 13. Individual deep-sea coral, most likely a gold coral on a vertical face at Pioneer Bank.

sentry.20141207.215031163987.14397.tif
2014-12-07 21:50:31 lat:25.8228189 lon:-173.4528946
depth:542.198m alt:5.1413m hdg:358.92d
temp:7.5149C obs:0.020018V

Figure 14. At a depth of 542m at Pioneer Bank, a highly preserved site, Corallium, gold corals, and potentially a black coral are seen on the vertical slopes. This contrasts from the latter of images from heavily trawled sites.

The water column characteristics are very similar at all three sites. While there is latitudinal variations in sea surface temperatures the water column characteritics between 200 and 800 m, the preferred depth ranges for DSC of interest are nearly identicle. This shows that environmental factors are not the cause of differences in the presence and absence, or health of DSC at the different study sites. In addition we see temperature and oxygen changes between 300 and 800 m that correspond to increases in alkalinity measurements across the depth ranges (Thompson et al., 2014). Thompson et al., (2014) reported alkalinity (nTA) results from Maro Reef in the NWHI where nTA increased from ~2300 μmol kg^{-1} at 300 m to ~2380 μmol kg^{-1} at 800m. This suggest our total alkalinity results at Yuryaku Seamount, Bank 11 and Pioneer Seamount will fallow similar patterns and most important that a showling of the aragonite saturation horizon may have an impact over the depth ranges of DSC within the region.

Measurements of total alkalinity through the water column from each of the seamounts in the NWHI are used to define the aragonite saturation horizon and compare it to the current distribution of DSC. In addition, developing a model that predicts the aragonite saturation based on the oxygen and nutrient measurements of seawater as Feely et al., (2008) did off of the west coast of Oregon. Such a model could allow for the determination of the aragonite saturation state in the region using much easier and less expensive analyses. From a management and conservation perspective, the importance of determining the aragonite saturation state is that it could be a limit to the recovery of DSC. The Ω_A at 1 is neutral for coral skeleton growth, however changes in oceanic composition can alter this state so that at $\Omega_A > 1$ corals can continue to grow and build carbonate skeletons while at $\Omega_A < 1$ corals will not be able to grow skeletons. If the boundary where $\Omega_A = 1$ is rinsing in the water column, then the ability of DSC to recover from anthropogenic impacts is going to be more limited.

These results along with the new measurements will be used to test and validate the Feely et al., (2008) aragonite saturation model. Important variables that are being measured are total alkalinity, pH, and nutrient concentration,. Since the initial formulas were calibrated in an upwelling zone off of the coast of Oregon and the surveyed area is typically a low nutrient region, the calculated aragonite saturation state will be compared to the measured values using this new dataset along with WOCE data from the 1993 and 2006. The results collected in this study should help to improve the aragonite saturation state models for low nutrient environments of the NWHI. These results will better inform the management community about threats to DSC community and their ability to recover.

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